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THE UNIVERSITY CENTER FOR APPLIED INTEGRATIVE RESEARCH IN TRANSPORTATION

(SECURITY, SAFETY, RISK, COST, ENVIRONMENT AND SUSTAINABILITY)

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INTRODUCTION

Critical Transportation Issues

This country faces critical transportation issues that will have major impacts on the economy, the security, the environment and the standard of living for millions of Americans. The ability to grow the U.S. economy, face global competition and provide secure movement of products and people will be crucial over the next 10 to 20 years. Providing safe, secured and efficient transportation with high reliability must be accomplished, while preserving long-term sustainability of the communities and regions. An integrated university transportation research center shall be established to take the lead in finding solutions of these issues.

The Vision Of The Center

The Transportation Center of the University of Colorado will be an internationally enabled, U.S-centered technology and educational institute whereby multidisciplinary expertise can be applied to provide solutions for the nation's surface transportation issues. It will be based on its innovative research capability but with the goal of solving problems. The center will include resident researchers, teaching professors and special external experts to provide both the core competencies and the knowledge to be the national resource for surface transportation issues. The center will partner with local government and industry to ensure that its research will be practical and adoptable. We envision it will become the center of the university centers with its national and international outreach for exchange of expertise to be a major resource center for the U.S. Department of Transportation. (US DOT)

Location And Geographic Resources Of The Center

Located in Boulder, Colorado, it is at the center of national surface transportation activities. On the railroad front, Fort Collins-Denver-Colorado Spring forms the major crossing areas of the nation's freight railroads. There are ample experience and knowledge of railroad safety and route management nearby and connected to the university as a knowledge base. Further south to Boulder in Pueblo is the Transportation Technology Center (TTC), home of national and international rail car test ground. TTC has tested transit rail cars from New York City to Hong Kong since it became independent from US DOT in 1988. Because of its large layout and modern facility, it has become the preferred center of railcar dynamic testing in the world. For urban transportation, Denver has the most extensive modern light rail network in the country.

Furthermore, it represents an extensively integrated rail and bus operation. Utilizing recent research results in ITS, the Denver RTD has developed a regional bus management system coordinated with the Denver Light Rail System in a real time fashion, leading the country in bus/rail service coordination. These are parts of the setting of the Transportation Center for the University of Colorado and certain formal endorsements and association will be completed at the establishment of the center.

The Denver-Boulder area is also the hub of highway design and construction activities. For example, the major US east-west Highway 70 intersects several north-south highways with numerous elevated over-pass and clover leaves to accommodate the heavy travel demands of one of the busiest wide spread metropolitan area in the USA. In addition, the 70 West Corridor poses the difficult challenges for providing easy access to the Rocky Mountain Range that requires innovation in tunneling or new material elevated structures, the subject of new planning and research. The University of Colorado plans to complete an infrastructure reliability prediction model for optimizing the highway maintenance, using a network of 4 interconnecting highways and 14 bridges around Boulder-Denver area (see Figure 1).

National and International Orientation

The proposed Center will take advantage of the International Association for Bridge Maintenance, Safety and Management (IABMAS). This association of more than 300 members from 37 countries and over 30 supporting organizations, deals with transportation infrastructures. The IABMAS is led by a faculty member in the University and was active in the official investigation of the Kobe Earthquake and surrounding highway damages. Another faculty member is actively involved in a post-September 11 analysis of the collapse of the World Trade Towers in New York on request by the National Institute of Standards and Technology (NIST). There is ample structure expertise's with the university to apply to the surface transportation research.

CENTER THEMES

The proposed themes for the Transportation Center of the University of Colorado are:

<u>Transportation Security</u>

Personal Security

Since the 9/11, the US Department of Transportation has funded many security-oriented research projects. The fact that mass transit always carries a large number of passengers makes it a vulnerable target of a terrorist attack. Both the Paris bombing incident (1998) and the Tokyo sarin gas attack (1996) serve as a grim remainder of what could happy to any major metropolitan city in the US or worldwide. The Federal Transit Administration has undertaken a number of critical areas of passenger security research ranging from emergency communication requirements to hardening of civil facilities. Universities have the additional role to fill in looking further into the broader impacts and requirements of prevention of attacks and post crisis management of an incident. The Federal Highway Administration has also undertaken security research. The major areas for research concerning passenger security for the proposed center are:

- Establishing emergency procedures for passengers/travelers to follow if an incident has occurred, communicate the procedure to them before hand and learn how to implement them.
- Training the management or police personnel for transit system or highway of crisis management and crowd control.
- Minimizing casualties by orderly evacuation and disperse of passengers/travelers from the scene of the incident.
- Pre-established medical and care centers around most probable location of incidence.

System Security

In terms of physical structure the vulnerability of transportation structures to natural and man-made disasters, usually results in the collapse of a structure in a crowded urban area. This not only causes considerable human casualties but also has a severe impact on the socio-economic stability of the area. A recent report by the American Society of Civil Engineers found that 27.5% of highway bridges in the U.S. have deteriorated to an extent that they are considered structurally deficient or functionally obsolete (ASCE 2003), becoming more vulnerable to a terrorist attack. Research of the future security of the physical transportation systems will include:

- Hardening of the bridges and tunnel in critical security areas. In transit systems for example, under-water tunnels in New York City NYCT or San Francisco BART are clearly necessary; the question is how to accomplish that in minimal time and low cost.
- Protection schemes and devices for the electrical power grid and communication control systems for rail transit is another necessity. How to accomplish these with proper design of software and hardware.

To address these above issues, the center will take the approach in the following sequence:

- Refine and select critical security vulnerability areas in highway and transit
- Outline innovative and practical counter-measures
- Define solution options with the center's industry partners.

In addition to the vulnerability of transportation structures with regard to earthquakes, roadside fires are of great concern if we recall the recent tunnel disasters in Europe (Channel fire and the Montblanc tunnel fire). Furthermore, accident conditions include vehicular collisions and crashes with roadside safety devices, such as guardrails and support structures for luminaire devices and signposts. These different accident conditions are in the forefront of homeland security aspects in search of better protection of our transportation infrastructure.

A system approach to address the risk, safety, and life-cycle costs of transportation facilities requires good analytical models that can predict and simulate the deterioration process of transportation structures and the vulnerability of these structures to natural and man-made disasters. Such models can be used for risk assessment and system reliability analysis of large-scale transportation systems and networks, life-cycle analysis of transportation structures, and the development of health-monitoring and intervention strategies. Computational simulations of dynamic events form the core of safety assessments for extreme events. Computational mechanics and nonlinear dynamic finite element analysis provide the theoretical and analytical tools to perform crash, earthquake, and fire simulations of structural components and systems in support of forensic engineering and the development of new design concepts for extreme events. These computational models rely upon basic materials and deterioration science, material constitutive laws, facture mechanics, and finite element techniques

Infrastructure Safety and Maintenance

Risk Analysis

Risk and safety assessments of the transportation facilities and systems are continuations of the discussion from the above section. Traditional risks of accident and equipment malfunction are now augmented by the possibility of deliberate acts of terrorism.

The public has traditionally accepted risk of mortality and morbidity from highway travel of two to three orders of magnitude greater than from other transportation modes. Chief in the minds of the public are three factors, each highly correlated with observed decision traits. One of these is *dread* of the event, for which study groups have associated the feelings of catastrophe, inequitable, difficult to prevent, threatening to the future, and involuntary. Each of these is associated with events of transportation of the mass, such as airplanes and trains, and much less so with automobile travel. A second factor is *technological stigma,* which is associated with the unknown, uncertainty, a lack of observability, lack of immediacy, and the lack of trust in the source of the information. Finally, the *number of people exposed* is a critical factor. Studies have shown this is very highly influenced by the number of people affected by single incidents.

We propose to conduct risk analysis of physical systems by focusing on:

- Its characteristics of induce fear of “dread” to the public even if its infrastructure value is not high.

- Increasing the observability to any vulnerability of the surface transportation facilities/infrastructure, so that the transparency helps to make it safe and secure.

- Investigate designs to reduce the over-exposure of the number of traveling public in a given public transportation facility- future design of facility that reduces security and safety blind spots.

- The hardness of the facility

A recent study team of the National Academy of Engineering (National Research Council 2002) has investigated in depth the ability to increase safety and security of facilities with various technological solutions. It concludes that there are essential elements for making facilities, especially public ones, safe and less vulnerable to attack. Many of their recommendations, including those on lifelines and networks, will need to be evaluated. In addition, a small NAE study group concluded that isolating systems and preventing acts of terrorism would both be essential ingredients in the security of large-scale systems. Lessons from a classic NAE study in increasing the security of physical facilities at U.S. embassies worldwide can also provide valuable guidance with respect to transportation systems.

Significant research over the past two decades on natural hazards and disasters has produced valuable lessons for protection of the built environment (Mileti 1998). While much of this information is not directly suitable for terrorist-instigated security issues of facilities, many results in mitigation, preparedness, response and recovery do bear directly on the transportation facility security issue (Levinson and Granot 2002).

With regard of the hardness of a facility, usually experimental research provides the essential means to validate and calibrate analytical models and evaluate the performance of structures under extreme load conditions. Without adequate test data to calibrate, most analytical models are not reliable as predictive tools and are unable to capture the fine details of a failure process. A hybrid test method that combines physical testing with model-based simulation provides a cost-effective means to assess the behavior of large transportation structures without ignoring the detailed behavior of its critical components. In such a test, a large-scale structural system can be modeled analytically in a computer, while a critical component of the system is tested either statically or dynamically to assess its performance under extreme loads

The University of Colorado at Boulder has a state-of-the-art fast hybrid test facility in the Structures Laboratory. The facility is also well connected to other large-scale structural testing facilities in the U.S., Europe, and Asia both physically via a high-performance information network and through personal contacts. It is thus well positioned to serve as a resource center to address the most challenging problems related to transportation facilities.

The University of Colorado at Boulder has had a world-class geotechnical centrifuge in operation since 1988. This 400 g-ton, 6-m radius machine can accommodate a 2-ton payload and test it at an acceleration level as high as 200 g. It has been used in research in many static and dynamic applications. For instance, by activating a shake table carried on the centrifuge test platform, effects of earthquakes on the stability of earth dams can be studied. On the other hand, by using scaled quantities of explosives embedded in the soil sample, effects of blasting on buried structures can be readily identified.

System Safety and Life-Cycle Assessment

The prioritization of scarce funds among the multitude of urgently needed transportation maintenance activities is a major problem that transportation agencies everywhere are facing. Despite all the difficulties in using the minimum expected whole life costing as the optimization criterion for the prioritization of funds, transportation authorities are committed to it. Thus far, however, the implementation of this criterion in management of transportation systems has been very limited.

Current transportation management systems, including the two most advanced bridge management systems in use in the United States, Pontis and BRIDGIT, are based on very restrictive assumptions. Due to these assumptions, these systems are not able to: (a) capture the propagation of uncertainties during the service life of transportation structures; (b) integrate reliability and life-cycle cost; and (c) cost-effectively manage networks of aging and deteriorating structures. Therefore, further research is immediately needed to overcome these difficulties by optimizing management decisions for transportation networks based on simulated time-dependent performance and life-cycle cost.

One of the objectives of the proposed center is to further develop system safety and lifetime assessment and cost models for transportation structure networks based on the minimum expected lifetime cost criterion. The background on these topics is already in place. However, further developments are urgently needed for advancing the states of the art and practice in management of the transportation infrastructure. Experience in incorporating health monitoring and inspections on the assessment of structural safety of bridge systems has been acquired over the last decade at the University of Colorado, resulting in novel time-dependent safety and maintenance models.

The proposed center will investigate a new long-term transportation infrastructure model for predicting life-cycle cost considering multiple-objective optimization for management. This model will provide a decision tool that optimizes actions (inspection, repair, maintenance, replacement) on transportation infrastructures for multiple user-specified performance criteria.

Safety and Security of Infrastructure and Network

A primary objective is to develop a model-based simulator for optimizing management decisions for transportation networks based on simulated time-dependent performance and life-cycle cost. Uncertainties in loading, environment, resistances, deterioration processes, and maintenance costs will be included. An objective and yet practical definition of an optimum lifetime management process for transportation networks based on minimum expected lifetime cost of maintenance interventions is proposed. The goal is to determine and implement the best possible management strategy that ensures an adequate level of transportation infrastructure network reliability and serviceability at the lowest possible life-cycle cost. The proposed simulation model will also capture the system effect due to loss of functionality of an individual structures or a group of structures in the network. Therefore, this novel approach will be able to solve problems characterized by abrupt discontinuities including such phenomena as loss of connectivity of individual structures in the network.

The framework for optimizing management decisions for transportation networks based on time-dependent performance and life-cycle cost will be based on a multiple-objective formulation balancing the reliability of individual structures in the network, the overall reliability of the network, and the lifetime cost of maintenance interventions. Such an approach is in an initial stage of development at the University of Colorado using a real transportation network of 14 bridges connecting Boulder to Denver as indicated in the adjacent figure:

The proposed activity will advance discovery and understanding of life-cycle and network approaches to maintenance and management of transportation infrastructure and create the basis of a new generation of transportation infrastructures management systems where optimal management decisions in terms of life-cycle cost are made at the network-level while explicitly taking into account the propagation of uncertainties during the entire service life of each structure in the network.

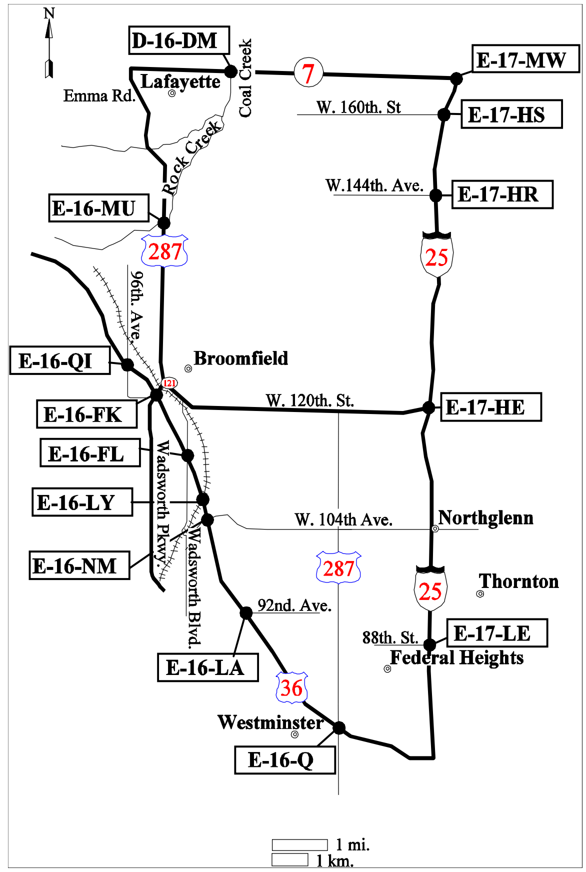


Figure 1 *A Simulator for Optimizing Highway and Bridge Management Decisions in Denver/Boulder*

Infrastructure Investment and Maintenance

The subjects of *Life-cycle Cost and Project Delivery Alternatives* for transportation projects hold the key for proper future investments and returns. We have historically experienced significant cost overruns from the stage of conceptual planning estimates. A recent study of 258 infrastructure projects spanning a time period of more than 70 years found that project costs are underestimated in approximately 90% of the projects, and the actual costs averaged 28% higher than estimated on this sample (Flyvbjerg et al, 2002). Although highway projects fared better than rail and fixed-linked projects, the sample still displays an increase in project costs of more than 20%. Recent high profile highway projects, such as Boston's Central Artery/Tunnel (the "Big Dig") and Virginia's Springfield Interchange have made engineers, contractors, and public taxpayers acutely aware of the problem. For example, the Big Dig was estimated at a cost of $2.6 billion (1982 dollars) and is expected to be completed at a cost of $14.6 billion (2002 dollars) with completion anticipated in 2005 (NAE 2003). Additionally, it can be argued that construction cost estimating on major infrastructure projects has not been increasing in accuracy over the past 70 years. The underestimation of cost today is in the same order of magnitude that it was then.

New ideas and techniques need to be developed to improve this area where no learning seems to have taken place. Cost estimation practices need to improve for many reasons. Projects are often cut in scope or canceled altogether due to other projects exceeding their budgets. This persistent cost underestimation reflects poorly on the industry in general, but more specifically on engineers.

The root cause of inaccurate cost estimating on mega-projects (projects over $100 million) can stem from a multitude of reasons. Managing the capital construction of mega-projects requires the coordination of a multitude of human, organizational, technical, and natural resources. Engineering and construction complexities can include a lack of information on the extent of utility impacts, required environmental mitigation, maintenance of traffic requirements, work hour restrictions, etc. Quite often however, the engineering and construction complexities of such projects are overshadowed by economic, societal, and political challenges. In addition to these challenges, a number of observers have suggested that project estimates have purposely been misrepresented in an effort to secure project approval.

Alternative project delivery strategies offer the opportunity for early cost knowledge and construction innovation. While alternative project delivery approaches are not yet commonplace in public transportation projects, there is a great potential for improved management of cost and schedule with the alternative delivery methods. For example, ISTEA authorized the FTA to select four transit projects to participate in the FTA Turnkey Demonstration Project Evaluation Oversight. The programs selected are: Baltimore Light Rail Extension; San Juan Tren Urbano Rail; El Segundo Del Norte (Green Line) Station; and the BART Airport Extension. Documented evaluations of these projects could potentially provide important input into this study. The figure below summarizes some of the delivery approaches that may result in more accurate cost estimation and management.

Project Delivery Approaches

- Indefinite Quantity/Indefinite Delivery
- Construction Manager at Risk
- Design-Build Contracts
- Design-Build Warranty
- Design-Build-Operate-Maintain (DBOM)
- Design-Build-Operate-Maintain-Finance (DBOM-F)
- Performance-Based Total Asset Management Contracts

Procurement Approaches

- Bid Averaging Method (BAM)
- Alternative Bids/Designs
- Request for Proposals
- Cost Plus Time (A+B)
- Multi-Parameter Bidding (A+B+Q)
- Best Value

Contract Payment Approaches

- Disincentive or Penalty Contracts
- Incentive Contracts
- Incentive/Disincentive Contracts
- Lane Rental Contracts
- Active Management Payment Mechanism
- No Excuse Bonus Contracts
- Lump Sum Contracts

By addressing these alternative delivery strategies with a focus on cost estimation and management, the center will provide engineers with better strategies, tools and techniques for cost management of our nation's infrastructure. Many lessons can be learned from an international exploration of these topics. Countries outside the United States face the same problems with growing infrastructure needs, inadequate public funds and insufficient or diminishing staff. These countries have developed alternative delivery strategies that offer great promise in the U.S. Through an international research collaboration, there is great potential for us all to become better stewards of our public resources.

People, Energy and Environmental Sustainability

Modern transportation systems cause or contribute to a wide range of environmental problems, including local and regional air pollution, surface and groundwater contamination, habitat and ecosystem disruption and climate change. Significant impacts arise at all stages in the *life cycle* of both vehicles and road and railway infrastructure: emissions of air pollutants and greenhouse gases from vehicle manufacture and roadway construction and maintenance; emissions from vehicle use; deposition and resuspension or runoff of metals from brake and tire wear; surface and groundwater contamination from brake fluid, antifreeze, oil and grease; and emissions and solid waste from vehicle and battery scrappage and from pavement or railway demolition.

Among these environmental impacts, air pollution concerns have historically imposed the most significant constraints on transportation infrastructure and technology. Air pollution and climate change are likely to be the most important environmental drivers for alternative transportation modes and technology improvements in the future. Over the past three decades, significant progress has been made in reducing the rate of emissions of carbon monoxide, volatile organic compounds and nitrogen oxides from new vehicles. Nevertheless, as of 2000, 121 million people in the U.S. lived in communities that failed to meet National Ambient Air Quality Standards for ozone, carbon monoxide or PM10 (fine particulate matter less than 10 microns in aerodynamic diameter) (TRB, 2002). The transportation sector accounts for a major share of the emissions associated with each of these pollutants (EIA, 2002. Future growth in transportation demand threatens to outpace environmental mitigation efforts that have been carried out to date. By 2025, annual passenger-miles traveled is expected to increase to 8.4 trillion miles, from 5 trillion miles in 2000, and freight transportation to expand by almost 30%, to just over 5 billion ton-miles (TRB, 2002).

The Surface Transportation Environmental Cooperative Research Program Advisory Board, which was established pursuant to a congressional mandate in TEA-21, recently concluded that major new investments in environment research are needed “to support the nation’s growth and meet public expectations for improved transportation system performance” (TRB, 2002).

Among the local and regional-scale air pollution problems associated with transportation, research on fine particulate matter and air toxics is particularly urgent. Current EPA standards are based on epidemiological evidence linking mortality and morbidity to PM2.5 mass concentrations, but significant uncertainties exist about how the size and composition of PM influence health risks (NRC, 2001).

EPA estimates that 100 million people live in areas of the U.S. where the combined upper-bound lifetime cancer risk from hazardous air pollutants emitted by mobile sources exceeds 10 in a million (EPA, 2002). Improved characterization of the composition and distribution of toxic air pollutants from mobile sources is thus needed to support comprehensive *risk assessments* and design cost-effective air pollution mitigation strategies (HEI, 2000). For both PM and air toxics, research is needed to quantify personal exposures to transportation-related air pollutants.

Personal exposure data are especially critical for sensitive subgroups, including children, the elderly, those with cardiopulmonary disease and pregnant women

In the past, environmental assessments of infrastructure plans and projects have often focused on local-scale air quality impacts of primary pollutants such as CO, with results aggregated over the transportation corridor. Environmental assessments for transportation systems need to be expanded to additional pollutants, such as fine particulate matter and air toxics, and to the full range of scales over which impacts occur. Ozone and fine particulate matter can form and be transported over distances of hundreds of kilometers, so the impacts of transportation systems on these pollutants are best examined on regional scales. Improved tools are needed to model the impacts of transportation systems on both finer scales and over larger regions, including, e.g., added air pollution from induced travel demand and land use changes.

Development of Energy Scenarios and Sustainability

The basic tenet of sustainability has been defined by the United Nations: “meet the needs of the present without compromising the ability of future generations to meet their own needs”(WCED 1987). One of the major challenges of long-term sustainable development is the balance of energy sources and uses. Oil, coal and natural gas account for the vast majority of the energy supply for transportation systems and electricity production, the latter being an important mass transportation energy source and a promising source for hybrid vehicles and hydrogen fuel cells. Transportation is the single largest sector of energy use in the United States, and therefore increased efficiencies will be vital as the supply of the resources mentioned begin to be depleted. Efficiencies of current modalities will be important, but so will new modes of transportation, altered behavioral patterns and new concepts of virtual presence.

The University of Colorado, Boulder, Center of the American West (CAW) provides an arena for regional transportation energy analysis. The settlement of the Trans-Mississippi West provides an extremely useful case study in a region in which changes in the technology of transportation underlie every step and stage of economic development, and the use of energy from fossil fuels has been the most consequential factor in the transformation of society and economy in the last century, with the free and unrestricted use of automobiles governing the shaping of the landscape. The Center has recently completed a comprehensive study and produced a report, *What Every Westerner Should Know About Energy*, written by Patricia Limerick, Claudia Puska, Andrew Hildner and Eric Skovsted. The study was made possible by the Hewlett Foundation.

In 2005, CAW will host, in collaboration with several federal agencies, a conference on “the Role of Engineers in the Shaping of the West,” and transportation issues will be prominently featured in that conference and resulting publications. The life-cycle analysis of transportation structures is fundamentally a historical enterprise. Combining the approaches and epistemologies of engineers and historians seems certain to produce fresh and innovative understandings.

There is no single, universally accepted definition of sustainable transportation, but the concept generally invokes a system that can meet mobility needs for all (including the elderly, disabled and economically disadvantaged) and be continued into the foreseeable future without harm to the environment and without depletion of the resources on which the system depends (Benfield and Replogle, 2002). Achieving sustainability in the face of the transportation sector's heavy reliance on fossil fuels will be a challenging task. Strategies that are generally viewed as promoting sustainability include increasing modal diversity, emphasizing transit, walking and biking; incentives to use efficient transportation modes; improved integration of transportation and land-use to minimize demand for single-occupant vehicle use; streamlining connections between modes; and pricing transportation so that it reflects full environmental and resource costs. The 1991 Intermodal Surface Transportation Efficient Act (ISTEA) and the 1998 Transportation Equity Act for the 21st Century (TEA21) and the upcoming SAFTEA endeavor to promote these strategies. To improve their effectiveness, research is needed to better quantify the full life-cycle costs and benefits of alternative transportation modes and infrastructure designs. As security issues receive increasing priority in transportation system design, both synergies and tradeoffs between enhanced security and sustainability need to be explored.

Financial Incentives for Sustainable Transportation

Public funding for the development of transportation infrastructure made an enormous difference in the history of the American West. It will surely be of equal importance (either by its absence or its presence) in the national and international future, and that situation makes a reckoning with the word "public" in the phrase "public transportation" an urgent priority. There are two elements for sustainable transportation: the desirability of having such a system and the financial incentives for doing so. While much research has been conducted on the first, relatively little have been done to explore the financial incentives for constructing sustainable transportation systems.

One financial innovation is to negotiate a comprehensive partnership, rather than award construction to the lowest cost bidder. This has been practiced in many parts of the world, including to a limited extent in the United States. The paragraph below describes an example of an owner-contractor partnership agreement in The Netherlands, giving preference to bidders of public works projects who will construct an environmentally sustainable system. Similar methods were used in the building of West Rail of Hong Kong and elsewhere where environmental standards are stringent and consequently higher construction cost may require. . We hope future research can be conducted to extend this practice to building sustainable transportation systems.

- The High Speed Rail (HSR) system in The Netherlands is being constructed in to connect the French TGV and German ICE to the Dutch cities of Rotterdam and Amsterdam. The environmental requirements of such large scale project are among the most restrictive in Europe. An American firm, Fluor, has led a consortium that has proposed environmentally friendly construction and taken responsibility for subsequent operation that will satisfy the stringent environmental and noise requirements in The Netherlands. This contract was negotiated with optimal construction and environmental performance, rather than lowest bid construction.

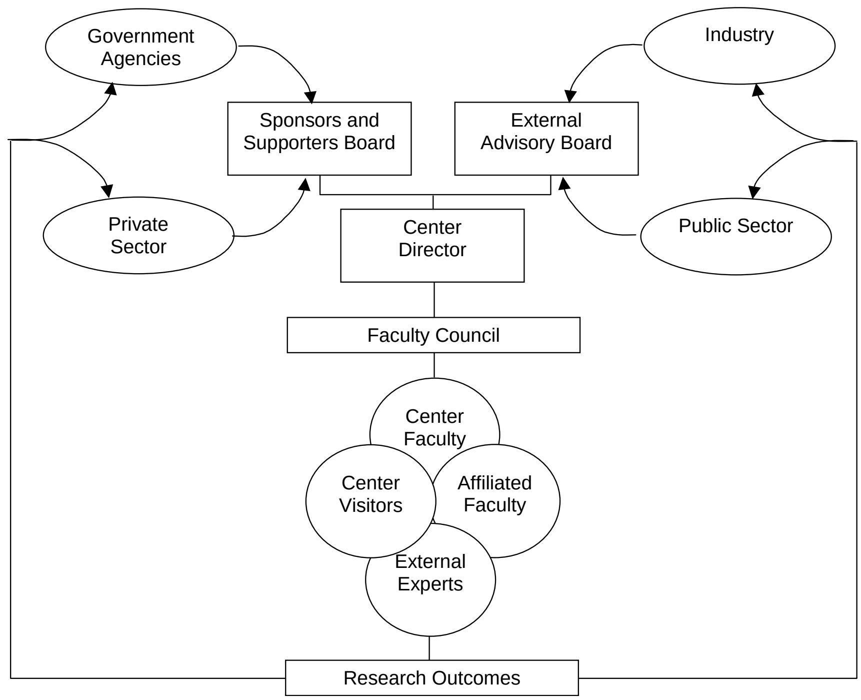
A second example of innovative funding relates to the large picture of how to reduce carbon waste produced by industrial products. European investment banks and the World Bank are using Carbon Credits as an investment tool to compensate enterprises that are introducing new technologies to reduce the Green House effect. According to figures in the Financial Times in October 2003, a $0.98 credit may be traded on the open market for each tonnage of carbon that would otherwise be produced using old technologies. This scheme is benefiting oil and energy firms who are collecting such credits before projected future pollution penalties set by EU and other international bodies. Carbon credit is being traded as a real financial instrument; however, the credit goes to the manufacturer, not the end user. It is hoped that future research can draw together all the players involved with public transportation as incentives are sought for financing a sustainable system.

The two above examples demonstrate how one can encourage public investment in building sustainable transportation systems. However, much research effort needs to be devoted to this area of innovative financing for transportation systems. A sound financial incentive will secure a base for long-term sustainable development.

The allocation of public funding, and to a large extent private funding, in a free and democratic society based on the principles of capitalistic entrepreneurship present demanding challenges with respect to both transportation security and sustainability. Security and risk perception and trade-offs across societal choices will have enormous impact on our country's financial resources in the transportation sector. A broad comprehensive approach that has its roots in sound technological principles is urgently needed to guide future investment. Our country must have the knowledge to provide this guidance, and the wisdom derived from this knowledge to encourage free enterprise incentives concomitant with the goals of service, efficiency, security and sustainability. We must never forget the Native American saying, “The earth was not given to us by our ancestors, it is borrowed from our children.”

ORGANIZATION AND MANAGEMENT STRUCTURE OF THE CENTER

While a detailed description of the management structure of the Center is premature at this time, key attributes are conveyed in the figure below.



To ensure vision as well as focus for the Center, input from government agencies, industry and the public and private sectors must be formalized. These will be infused directly into the *Sponsors and Supporters Board* and the *External Advisory Board*, both through solicitation of views and through members of those constituencies serving as members of the boards. These boards will meet regularly with the *Center Director* as well as the *Faculty Council* in order to determine what projects should be initiated and how they will be staffed. The *Council* in turn will directly interface with the four principal resources of the Center, the Center Faculty, the Affiliated Faculty, the Center Visitors, and the External Experts, which form the core resource for conducting exploratory studies and research. Outcomes of the research and policy studies will then be directly transferred to government agencies, industry and private and public sectors.

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APPENDIX A: Physical System Performance

The University of Colorado at Boulder has renowned faculty in the area of performance of structural and geotechnical systems. Three aspects of physical system performance are of special interest for transportation systems, and are among the most active and acclaimed areas of expertise among the faculty. These are described briefly below.

Fracture and Fatigue

Fracture mechanics plays a most important role in the service life assessment of transportation facilities. Steel structures are prone to subcritical fatigue crack growth originating at poor welds, and aggravated by repeated loads, weathering (corrosion), and overstressing. In particular, steel bridges built in the early 1960's are likely to have a high strength steel, but low fracture toughness, which may result in potential collapse.

Structural Deterioration

The deterioration of concrete structures manifests itself primarily through the formation of cracks. Whereas one would expect any reinforced concrete structures to develop cracks, shear failure (through cracking) is still poorly understood and in some cases critical, and nonlinear fracture mechanics concepts must then be used. Furthermore, chloride diffusion or carbonation can lead to a drop in the concrete Ph, which depassivates the steel, thus removing its inherent protection against corrosion. Once steel corrosion starts, there is a swelling of the steel resulting in cracking and eventually spalling (potholes) of the concrete. This can only be effectively addressed by fracture mechanics. Finally, modern bridge rehabilitation with fiber-reinforced polymers (FRP) has to rely on fracture mechanics to properly understand the various failure modes of these hybrid structures.

Foundation Failure

The performance of a transportation structure under extreme loads depends very much on the behavior of its foundations. For example, liquefaction and soil-structure interactions have a critical impact on structural performance under a major earthquake event. The deterioration of a transportation structure can also be caused by foundation settlements and scouring. Centrifuge testing is an important tool to characterize the constitutive behavior of soils and predict their behavior under different loading conditions. The concept of centrifuge modeling is quite simple. By testing an n^{th} scale model under an acceleration equal to n times Earth's gravity, the important effects of gravity loading on earth structures and the control of soil's strength and stiffness properties can be faithfully simulated. Centrifuge testing can be used to study the safety of prototype designs and to validate analytical and numerical models. Thus, it can play a key role in the transportation research center because of its versatility in simulating various events that impact on the security of the transportation infrastructure. The issues of cost effectiveness in novel designs of critical protective structures and strengthening of existing structures can be conveniently addressed.

APPENDIX B. Summary of Activities

1. "An Established and Organized Program"

THE INTERNATIONAL CENTER FOR APPLIED INTEGRATIVE RESEARCH IN TRANSPORTATION

Over the next two decades, transportation issues will have major impacts on the economy, the security, the environment and the standard of living for millions of Americans. In particular, global economic competition and the assurance of secure movement of products and people will become crucial within the next 10 years. Concomitantly, transportation systems must sustain our communities and society as a whole. An integrated transportation research activity has been established at the University of Colorado to take the lead in addressing these issues, and a formal Center is being planned.

The Vision of the Center

The Transportation Research Center at the University of Colorado will include resident faculty researchers, special external experts, and students to provide the core competencies and the knowledge to be a national and international resource for planning and implementation of surface transportation systems. In addition, the Center will partner with local and regional government agencies and transportation enterprises to ensure that its research will be practical and adoptable. The Western mountain states are a very appropriate region for a national transportation center. The region has highly varied terrain, significant climate variability, long travel distances, as well as unique air quality and land development concerns. The need for integration of transportation systems to serve rapidly urbanizing, rural, and isolated mountain areas along with interregional travel provides opportunities for novel research and development. Furthermore, the Center will draw upon transportation expertise from around the world in bringing the greatest possible knowledge to bear on the transportation challenges of our country; while at the same time Center outreach will be directed to adapting the Center's integrated approach to transportation problems throughout the country and in other parts of the world.

Location and Geographic Resources of the Center

Colorado is the center of significant national surface transportation activities. The Fort Collins-Denver-Colorado Springs corridor has major crossing areas for the nation's freight railroads, and there are ample experience and knowledge of railroad safety and route management nearby. The Transportation Technology Center (TTC), home of national and international rail car test ground, is located south of the Denver Metro area in Pueblo, Colorado. Because of its large site and modern facilities, it has become the preferred center of railcar dynamic testing in the world. With respect to urban mass transportation, Denver has the most extensive modern light rail network in the country, and leads the country in bus/rail service coordination. The Intermountain region is also the hub of highway design and construction activities, supporting a network of major north-south and east-west interstate highways. The I-70 West Corridor poses especially difficult challenges for providing easy access to the Rocky Mountains and points west that require innovation in tunneling, right-of-way, and new materials for elevated structures.

Faculty at the University of Colorado have been engaged in significant research on transportation infrastructure for many years, and over the past five years there have been almost 50 independent projects supported at the level of approximately $1.5 million per year, as described below. By bringing these individual researchers together, the Center will be able to make a significant contribution to emerging needs for transportation systems in the West, the entire country and worldwide.

2. “$1m/yr Transportation Research Activities for the Past 5 Years”

RECENT TRANSPORTATION RESEARCH ACTIVITY (1999 – 2003)

Agency and topics	Number of projects	Funds Awarded
Colorado Department of Transportation (CDOT). Highway safety, highway infrastructure design and maintenance	15	$494,000
Colorado Local Technical Assistance Program for Roadway Infrastructure (LTAP). Roadway materials and testing	1	$750,000 (Total $1,500,000)
Federal Highway Administration (FHWA). Transportation infrastructure design, construction, and operation	9	$868,000
FHWA and CDOT. Highway/bridge safety and design	4	$2,400,000
National Cooperative Highway Research Program (NCHRP). Cost estimation and management, and best-value procurement for highway construction	2	$178,000
Washington State Dept. of Transportation. Design-build project evaluation	1	$120,000
Insurance Institute for Highway Safety. Methods to reduce crashes at rural high-speed intersections	1	$35,000
National Center for Excellence in Railway Mechanics, Sweden. Dynamics of train/rail/tie/ballast/sub ballast system under cyclic conditions	1	$95,000
National Science Foundation. Reliability and life-cycle analysis applied to design and maintenance of highways and bridges, durability of concrete.	9	$2,128,000
US Environmental Protection Agency. Air quality monitoring, estimation of exposure to volatile organic chemicals.	2	$236,000
California Air Resources Board. Modeling ozone episodes	1	$92,000
Federal Aviation Administration. Soil swelling and airport structure movement	1	$85,000
American Society of Civil Engineers. Optimal management of civil infrastructure	1	$5,000
Design-Build Education and Research Foundation. Lifecycle of transportation design-build projects	1	$45,000
TOTAL	**48**	**$7,486,000**

3. “5 Graduate Degrees (MS) Given in the Past 5 Years in Transportation Related Field”

Only master’s degrees are listed here. Doctoral degrees are given in Appendix II.

1999
Miyake, Masaru, “Cost-Based Maintenance Strategies for Structures”
Frank, Dean, “Nondestructive Evaluation and Inspection of Structures”

2000
Ge, Yu-Ning, “Finite element analysis of staged construction”

2001
Noh, Jinil, “Reliability Analysis of Fiber-Reinforced Polymeric Bridge Deck”
Anderson, Melissa, “Source Apportionment of Toxic Volatile Organic Compounds”

2002
Omachi, Yoshiaki, “Lifetime Bridge Reliability Analysis under Fatigue”
Kawakami, Yoriko, “Life Prediction of Damaged Bridges”
Chanvut, K. “Corrosion Protection Methods for Reinforced Concrete Highway Bridges”
Xie, Z.H. “A Comparative Study on Corrosiveness of Different De-Icing Agents (Magnesium Chloride, Sodium Chloride, and Caliber M1000)”
Cusson, R. “Durability Properties of Fiber Reinforced Polymer Bars under Low Temperature Environment”
Hoyland, Jorg “Analysis of collapse mechanisms related to the disaster at the World Trade Center, September 11, 2001”

2003
Sakulyanontvittaya, Tanarit, “Evaluation of ISCST3 and AERMOD for Modeling
Benzene Dispersion in Commerce City, 2003”
Shane, Jennifer, “Design-Build Highway Construction: An Examination of Special Experimental Project Number 14 Performance”
Won, Spencer. “Classification of Lifecycle Criteria in Design-Build Highway Projects”
Wormer, Jeffrey, “Three-dimensional nonlinear analysis of slope stability in heterogeneous soils”
Woodruff, Ryan, "Centrifuge modeling for MSE-shoring composite systems"

4. “3 Full-Time Faculty in Transportation Fields”

INFRASTRUCTURE SAFETY AND PERFORMANCE

Maintenance, Management, Reliability and Life-Cycle Performance

Dan M. Frangopol, Professor, Civil, Environmental and Architectural Engineering, Director, COALESCE (Consortium on Advanced Life Cycle Engineering for Sustainable Civil Environments), President, IABMAS (International Association for Bridge Maintenance and Safety)

George Hearn, Associate Professor, Civil, Environmental and Architectural Engineering

Structural Reliability and Life-Cycle Analysis

Ross B. Corotis, Denver Business Challenge Professor of Engineering, Civil, Environmental and Architectural Engineering, Structures Co-Director, Consortium on Advanced Life-Cycle Engineering for Sustainable Civil Environments

ENVIRONMENT AND ENERGY POLICY

Environment and Air Quality

Jana B. Milford, Associate Professor, Mechanical Engineering, Center for Combustion and Environmental Research, Center for Science and Technology Policy

History, Development and Energy Policies

Patricia N. Limerick, Professor, History, Founding Director, Center of the American West

FACILITY DESIGN

Geotechnical Engineering and Centrifuge Laboratory Testing

Hon-Yim Ko, Professor, Glenn Murphy Chair of Engineering, Civil, Environmental and Architectural Engineering

Materials Engineering and Fracture Mechanics

Yunping Xi, Associate Professor, Civil, Environmental and Architectural Engineering, Director, Colorado Local Technical Assistance Program (C-LTAP

Kaspar Willam, Professor, Civil, Environmental and Architectural Engineering

Victor Saouma, Professor, Civil, Environmental and Architectural Engineering

Dynamic Structural Analysis and Dynamic Structures Laboratory Testing

Benson Shing, Professor, Civil, Environmental and Architectural Engineering, Director, NSF Network for Earthquake Engineering Simulation Center

CONSTRUCTION MANAGEMENT

Construction Engineering and Management

Keith R. Molenaar, Assistant Professor, Civil, Environmental and Architectural Engineering

James E. Diekmann, Professor, Civil, Environmental and Architectural Engineering

TRANSPORTATION CENTER, UNIVERSITY OF COLORADO AT DENVER

Bruce N. Janson, Professor, Civil Engineering, CU-Denver, Director, Transportation Research Center

5. “20 Journal Publications in the Past 5 Years”

1999 – 13 publications

2000 – 12 publications

2001 – 10 publications

2002 – 9 publications

2003 – 28 publications

In addition to the above, there were numerous reports and conference presentations.

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Education

Ph.D.	*Civil Engineering*, University of California, Davis, 1982 (Environmental Engineering)
MS	*Civil Engineering*, University of California, Davis, 1980 (Environmental Engineering)
BS	*Civil Engineering*, University of California, Davis, 1977, (Summa Cum Laude)
BA	*Psychology*, Stanford University, 1967 (Honors)

Awards
- Clarence Eckel Faculty Achievement Award, CU, Dept. CEAE, 2001
- Faculty Appreciation Award, CU Multicultural Engineering Program, 2000-2001
- Distinguished Engineering Educator, (national) Society of Women Engineers, 2000
- Faculty Award for Women Scientists and Engineers, National Science Foundation, 1992-1997

Academic Experience
- 1998-present, Professor, Dept. Civil, Environ. & Arch. Engr., Univ. Colorado, Boulder
- 1989-1998, Assoc. Professor, Dept. Civil, Environ. & Arch. Engr., Univ. Colorado, Boulder
- 1982-1989, Asst. Professor, Dept. Civil, Environ. & Arch. Engr., Univ. Colorado, Boulder
- Registered Professional Engineer, Colorado #26151, since 1989.

Interests
Research and teaching in civil and environmental engineering, especially on the use of microbial processes to remove contaminants from wastewater and water supplies, to treat wastewater and biosolids for beneficial reuse, and to restore damaged environmental sites such as abandoned mines. Achieving greater diversity in the engineering workforce and academia by increasing participation of women and people of color.

Publications and Research
Over 50 papers in reviewed journals, conference proceedings, and books on sustainable remediation of acid mine drainage, nitrogen removal from water and wastewater, pathogen survival in wastewater recovery processes, biodegradation of toxic contaminants and health effects of land application of treated biosolids. Patent: “Biological Denitrification of Water.”

Teaching
Twenty courses in engineering. Sixteen Ph.D. student advisees graduated since 1989, 11 in academic positions. Director, NSF-sponsored environmental engineering Research Experience for Undergraduates Program, sponsoring eight summer interns per year.

Current Service at CU
Department Chair, VCAC, Faculty Advisory Boards: Center of the American West, Women in Engineering Program, interdisciplinary Environmental Engineering program.